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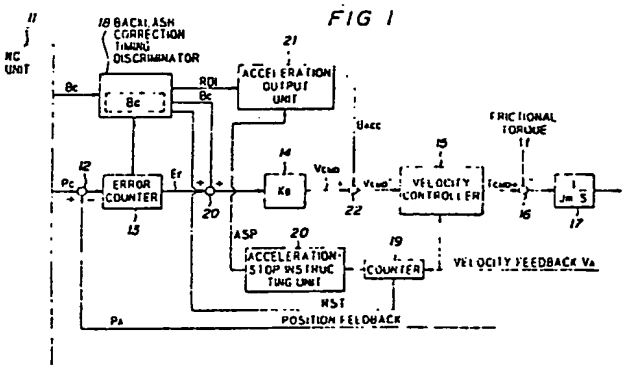
(54) SERVO CONTROLLER.

(57) A servo controller which, when the rotational direction of the servo motor is inverted, adds backlash correction data (B_C) to position deviation data (P_C) to generate a speed instruction (V_{CMD}) and adds backlash acceleration quantity (B_{ACC}) to the speed instruction to correct backlash. In order to terminate the backlash acceleration at a suitable timing, a counter (19) adds up the speed feedback pulses from a moment when the acceleration control is started, an acceleration stop instruction unit (20) monitors the added-up value of the speed feedback pulses, and an acceleration quantity output unit (21) no more produces the backlash acceleration quantity (B_{ACC}) when the added-up value has reached a predetermined value such as 2 or 3, thereby to complete the backlash acceleration control operation.

FIG 1



EP 0 389 641 A1

DESCRIPTION

SERVO-CONTROL APPARATUS

Technical Field

This invention relates to a servo-control apparatus and, more particularly, to a servo-control apparatus capable of performing a backlash correction rapidly and of reducing quadrant projections produced as a result of friction and backlash.

Background Art

In order to correct for backlash of gears or the like when the direction of rotation of a servomotor controlling the feed shaft of a machine tool is reversed, or in other words, when the direction of travel of the movable element of the machine is reversed, preset backlash correction data is applied to position error data to generate a velocity command, and the rotation of the servomotor is controlled based on the velocity command. However, since the backlash correction data acts upon a velocity loop through a predetermined position gain K_P, the machine does not move immediately because of a delay in the servo-system. As a consequence, a quadrant projection is produced at the location where the direction of machining is reversed.

Accordingly, in order to diminish the effects of backlash and friction and reduce projections at quadrant changeover points at the time of cutting, it has been proposed to apply a suitable amount of acceleration

(referred to as "backlash acceleration") to the velocity command for a prescribed period of time. However, when an NC unit effects backlash correction at the same time that the backlash correction data is delivered to the servo side, the motor is not completely reversed in direction owing to the delay between the command and the servo-system. The unfortunate result is that bite-in is caused on the inner side. In actuality, therefore, the direction in which the motor rotates is monitored and backlash acceleration is applied at the timing of the reversal in direction of rotation. When control of backlash acceleration is carried out at the time of the reversal in motor direction, the occurrence of quadrant projections caused by backlash and friction in the machine system can be reduced considerably.

There are cases where the effect of a sudden change in velocity at the end of acceleration shows up at the cut surface in the form of inadequate smoothness if the amount of backlash acceleration is made constant over the entire period of application. Accordingly, it has been proposed to enlarge the amount of backlash acceleration at the start of acceleration in order to prevent inadequate acceleration, and thereafter reduce the amount of acceleration gradually with the passage of time to prevent a sudden change in velocity when backlash acceleration ends.

However, the backlash acceleration algorithm itself is open-loop control, and it is required that parameters

(the amount of backlash acceleration, backlash acceleration time, etc.) be set accurately for each and every machine.

In addition, optimum parameters change depending upon cutting velocity, workpiece weight, temperature, the condition of the cut surface, etc. Consequently, even if quadrant projections can be made very small under certain conditions, these projections can enlarge or cut-in can result on the inner side when cutting is performed under other conditions.

Accordingly, an object of the present invention is to provide a servo-control apparatus capable of eliminating backlash with the same parameters even if machine conditions and cutting conditions change, thereby making it possible to eliminate quadrant projections.

Another object of the present invention is to provide a servo-control apparatus capable of ending backlash acceleration at an optimum timing, whereby the amount of backlash acceleration can be made a suitable value and quadrant projections can be eliminated.

Disclosure of the Invention

In accordance with the present invention, the foregoing objects are attained by monitoring the accumulated value of velocity feedback and stopping backlash acceleration when the accumulated value becomes equal to a predetermined value.

Brief Description of the Drawings

Fig. 1 is a block diagram of a servo-control apparatus according to the present invention; and

Fig. 2 shows the results of measurement in a case where a machine tool is made to cut a perfect circle using the servo-control apparatus according to the present invention.

Best Mode for Carrying Out the Invention

Fig. 1 is a block diagram of a servo-control apparatus according to the present invention. Numeral 11 denotes an NC unit which generates a move command P_C every predetermined sampling time T_S, and which outputs an amount of backlash correction B_C when there is a reversal in the direction of the move command. Numeral 12 denotes a position error arithmetic unit for computing a difference between the move command P_C and a detected amount of movement P_A every sampling time. Numeral 13 designates an error counter for accumulating the difference in accordance with the equation

$$E_r + (P_C - P_A) \rightarrow E_r$$

and outputting a position error E_r. Numeral 15 denotes a velocity controller for outputting a torque command based on the difference between a velocity command V_{CMD}' and velocity feedback (actual velocity) V_A. Numeral 16 represents an arithmetic unit for computing a frictional torque T_f from a torque command T_{CMD} outputted by the velocity controller 15. Shown at numeral 17 is a machine system including a servomotor, which is the object controlled, a pulse coder, etc. The machine

system 17 is expressed by a transfer function (J_m represents motor inertia).

Numeral 18 denotes a backlash correction timing discriminator, and 19 a counter to which pulses generated by a pulse coder (not shown) are applied as the velocity feedback V_A in order to be counted during each sampling time period T_S. Numeral 20 denotes an acceleration-stop instructing unit for monitoring the accumulated value in the counter and outputting an acceleration-stop signal ASP when the accumulated value attains a predetermined value, e.g,. 2 - 3. Numeral 21 denotes a unit for outputting the amount of acceleration. An adder for adding the amount of backlash acceleration is shown at numeral 22.

The backlash correction timing discriminator 18 stores and holds the amount of backlash correction B_C supplied by the NC unit 11 when the direction of the move command is reversed. In addition, the discriminator 18 monitors the content (position error) E_r of the error counter 13 and detects the reversal in the direction of rotation of the servomotor in response to $E_r = 0$. In response to detection of the reversal in direction of rotation, the discriminator 18 outputs the amount of backlash correction B_C to an adder 20, outputs a signal RDI indicative of the reversal in rotational direction to the acceleration output unit 21, and outputs a counter reset signal RST.

The acceleration output unit 21 outputs an amount

of backlash acceleration B_{ACC} when the position error E_r becomes zero (RDI = "1"), and terminates the output of the backlash acceleration when the accumulated value of velocity backlash V_A becomes equal to a predetermined value (ASP = "1").

The overall operation of the apparatus of Fig. 1 will now be described.

The difference, which is calculated in the arithmetic unit 12, between the move command P_C and detected amount of movement P_A every sampling time T_S is integrated by the error counter 13 to obtain the position error E_r, after which the position error is multiplied by the position gain K_P to provide the velocity command V_{CMD}. The velocity controller 15 subsequently outputs the torque command T_{CMD} conforming to a velocity error, thereby rotating the servomotor.

When the direction of commanded movement is reversed under these conditions, the preset amount of backlash B_C is outputted by the NC unit 11, and the latter generates a move command PC in the reversed direction every sampling time T_S.

The backlash correction timing discriminator 18 holds the abovementioned amount of backlash correction B_C and subsequently monitors the content (position error) E_r of the error counter 13 in parallel with the servo-control processing described above. When the condition $E_r = 0$ is established, it is determined that the servomotor has reversed direction.

In response to detection of the reversal in rotational direction, the discriminator 18 outputs the held backlash correction B_C to the adder 20, outputs the rotational direction reversal signal RDI to the acceleration output unit 21 and outputs the counter reset signal RST to reset the content of counter 19 to zero.

The backlash correction adder 20 adds the backlash correction B_C and the position error E_r and applies the result to the position gain setting unit 14. The latter multiplies the result by the position gain K_P to generate the velocity command V_{CMD} conforming to the amount of backlash correction.

The acceleration output unit 21 outputs a constant amount of backlash acceleration B_{ACC} in response to the rotational direction reversal signal RDI. As a result, the adder 22 adds the amount of backlash acceleration B_{ACC} and the velocity command V_{CMD} and applies the sum to the velocity controller 15 as the true velocity command V_{CMD}'.

The velocity controller 15 computes the velocity error and outputs the torque command TCMD conforming to this velocity error, thereby rotating the servomotor 17 to rapidly correct backlash.

In parallel with the foregoing processing, the counter 19 accumulates the velocity feedback VA from the moment acceleration control begins (i.e., from the moment $E_r = 0$ is established). That is, the counter 19

receives, as the velocity feedback V_A, the pulses generated by a pulse coder (not shown) and counts these pulses during each sampling time period T_S of digital servo-processing.

The acceleration-stop instructing unit 20 monitors the accumulated value in the counter 19 and outputs the acceleration-stop signal ASP when the accumulated value attains a predetermined value, e.g,. 2 - 3. This causes the acceleration output unit 21 to stop outputting the backlash acceleration signal B_{ACC}, thereby completing backlash acceleration control.

The reason for terminating backlash acceleration when the accumulated value reaches 2 - 3 is as follows:

In digital servo-control, the sampling time T_S is on the order of 1 msec, and spatial resolution of the servomotor, which is dependent upon the resolution of the pulse coder, is on the order of 10,000/rev. Velocity is very low when the servomotor reverses direction (i.e., at the start of acceleration control). Consequently, the number of feedback pulses (velocity feedback) V_A every sampling time is usually zero and sometimes attains a value of one. Therefore, when it is detected that the velocity feedback V_A has attained a value of one and backlash acceleration is terminated, termination timing is too soon, a sufficient backlash acceleration cannot be applied and quadrant projections cannot be eliminated. Further, in an arrangement where backlash acceleration is terminated upon detecting that

the condition $V_A = 1$ has been established, the termination of backlash acceleration will occur if the condition VA = 1 is established due to slight vibration in the motor for some reason (such as an external disturbance or unsteady current). As a result, the amount of acceleration will be greatly inadequate and backlash acceleration control will lose its meaning.

On the other hand, if backlash acceleration is terminated after the number of feedback pulses (velocity feedback) V_A in the sampling time T_S is detected to have attained a value of two, the rotational velocity at this time will be 12 rpm. As a result, the timing for terminating acceleration will be too late, backlash acceleration will be excessive and cut-in will occur on the inner side.

Accordingly, in the present invention, the arrangement is such that the accumulated value of the velocity feedback V_A is monitored and backlash acceleration is terminated when the accumulated value becomes 2 - 3. With such an arrangement, timing for ending backlash acceleration can be made that at which the amount of backlash acceleration attains the optimum value without being hastened or retarded excessively and irrespective of some variation in load conditions, a variation in cutting velocity, etc.

Fig. 2 shows the results of measurement in a case where a machine tool is made to cut a perfect circle using the servo-control apparatus according to the

present invention. The dashed line indicates a true circle, and numerals 1, 2 indicate the results of measurement for a case where cutting is performed in clockwise and counter-clockwise directions, respectively. Quadrant projections and cut-in on the inner side are eliminated at quadrant changeover points 3a - 3d.

Thus, in accordance with the present invention, it is arranged to start backlash acceleration when the direction of servomotor rotation is reversed and end backlash acceleration when the accumulated value of velocity feedback becomes equal to a predetermined value of 2 - 3. As a result, timing for ending backlash acceleration can be made that at which the amount of backlash acceleration attains the optimum value without being hastened or retarded excessively and irrespective of some variation in load conditions, a variation in cutting velocity, etc. This makes it possible to eliminate quadrant projections and cut-in on the inner side.

CLAIMS:

1. A servo-control apparatus for generating a velocity command by applying backlash correction data to position error data when direction of rotation of a servomotor is reversed, and performing a backlash correction by adding an amount of backlash acceleration to said velocity command, characterized by comprising:

means for detecting reversal of the direction of rotation of the servomotor;

detecting means for detecting that an accumulated value of velocity feedback has become equal to a predetermined value after backlash acceleration is started; and

acceleration output means for outputting the amount of backlash acceleration when direction of rotation of a servomotor is reversed, and terminating output of the amount of backlash acceleration when the accumulated value of velocity feedback becomes equal to the predetermined value.

2. A servo-control apparatus according to claim 1, wherein said predetermined value is two or three.

FIG. 1

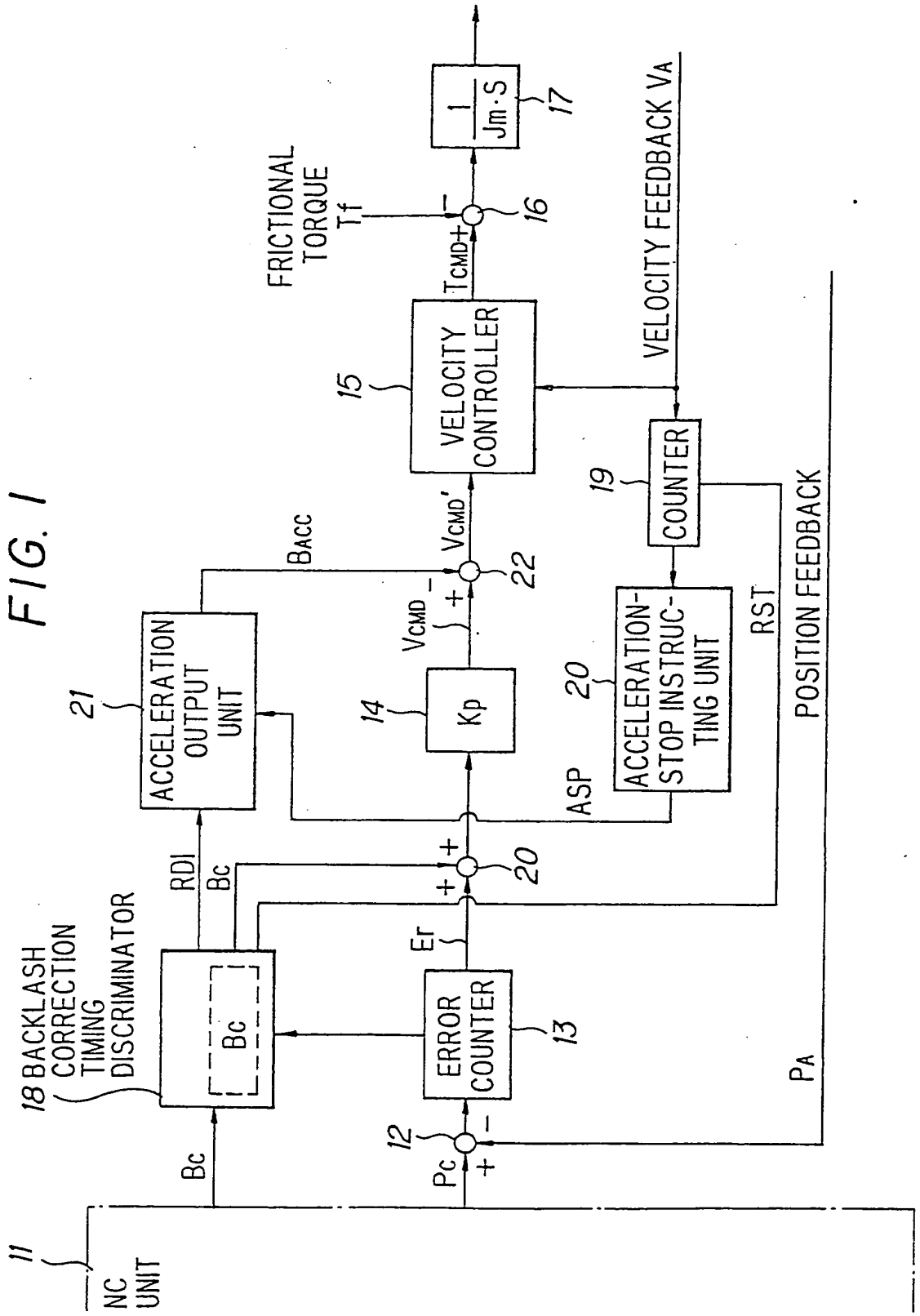
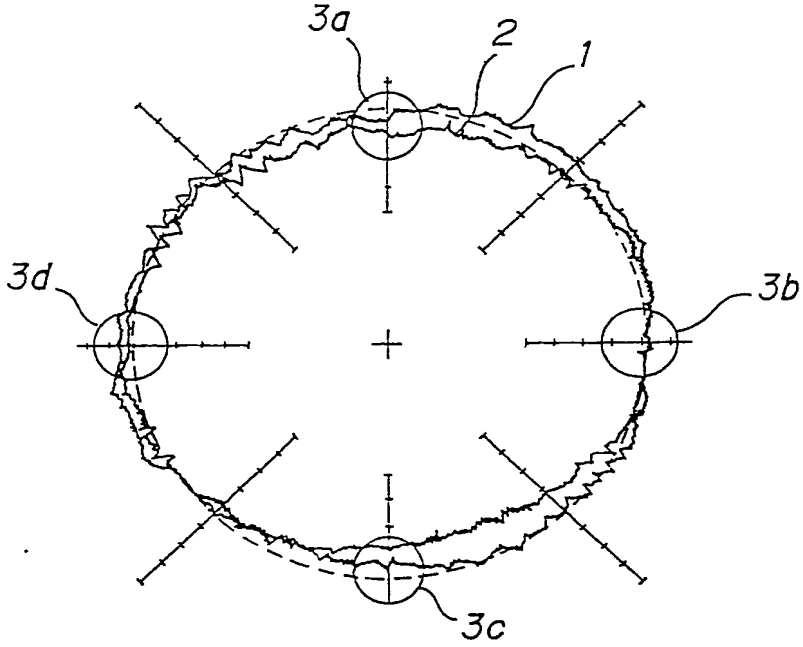

11
NC UNIT
Bc
Pc
12
+
−
ERROR COUNTER
13
Er
Bc
18 BACKLASH CORRECTION TIMING DISCRIMINATOR
RDI
ACCELERATION OUTPUT UNIT
21
BACC
+
+
20
VCMD −
+
22
VCMD'
14
Kp
ASP
20
ACCELERATION-STOP INSTRUC-TING UNIT
RST
19
COUNTER
VELOCITY FEEDBACK VA
15
VELOCITY CONTROLLER
TCMD
16
−
FRICTIONAL TORQUE Tf
1/Jm·S
17
POSITION FEEDBACK
PA

FIG. 2



INTERNATIONAL SEARCH REPORT

International Application No PCT/JP89/00969

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int. Cl[5] G05D3/00

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System [8]	Classification Symbols
IPC	G05D3/00 - G05D3/12, G05B19/18

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [9]

Jitsuyo Shinan Koho	1926 - 1988
Kokai Jitsuyo Shinan Koho	1971 - 1988

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category [15]	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
Y	JP, A, 63-156639 (MAHO A.G.), 29 June 1988 (29. 06. 88), Page 3, lower left column, line 15 to page 6, upper right column, line 9, & DE, A1, 3641888	1 - 2
Y	JP, A, 58-37709 (Washino Machine Co., Ltd.), 5 March 1983 (05. 03. 83), Page 1, lower right column, line 16 to page 3, upper right column, line 8, (Family: none)	1 - 2
Y	JP, A, 60-66694 (Hitachi, Ltd.), 16 April 1985 (16. 04. 85), Page 3, upper right column, line 5 to page 4, upper right column, line 1, (Family: none)	1 - 2
Y	JP, A, 58-214906 (Yasukawa Electric Mfg. Co., Ltd.), 14 December 1983 (14. 12. 83), Page 2, upper right column, line 16 to page 2, lower left column, line 8, (Family: none)	1 - 2

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
December 18, 1989 (18. 12. 89)	January 16, 1990 (16. 01. 90)
International Searching Authority	**Signature of Authorized Officer**
Japanese Patent Office	

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

Y	Utility Model Application No. 81688/1980 (Utility Model Laid-Open No. 10008/1982 (JP, U, 57-10008)) no Gansho ni saisho ni tenpusareta Specification and Drawing no Microfilm, Hitachi, Ltd. 19 January 1982 (19. 01. 82), Page 4, line 2 to page 7, line 19, (Family: none)	1 - 2

V. ☐ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE [1]

This international search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1. ☐ Claim numbers . because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claim numbers . because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically

3. ☐ Claim numbers . because they are dependent claims and are not drafted in accordance with the second and third sentences of PCT Rule 6.4(a).

VI. ☐ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING [2]

This International Searching Authority found multiple inventions in this international application as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.

2. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:

3. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:

4. ☐ As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

Remark on Protest

☐ The additional search fees were accompanied by applicant's protest.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

Y	JP, A, 49-128211 (Yasukawa Electric Mfg. Co., Ltd.), 12 April 1973 (12. 04. 73), Page 2, upper left column, line 11 to page 3, upper left column, line 19, (Family: none)	1 - 2
Y	JP, A, 61-178157 (Mitsubishi Electric Corporation), 9 August 1986 (09. 08. 86), Page 2, upper right column, line 2 to page 2, lower right column, line 11, (Family: none)	1 - 2

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